The Effects of Vibration in Structures

Preliminary Report of the Aberthaw Investigation

PRELIMINARY REPORT

OF

The Aberthaw Investigation

OF

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ABERTHAW CONSTRUCTION CO.
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Effects of Vibration in Structures

WHEN our study of vibration and its effects was undertaken with the purpose of determining how it might be eliminated or avoided in building construction, we were not unmindful of the complexity of the problem. We realized the difficulty of tracing effects to specific causes and of separating the manifold influences concerned in vibration. It is not surprising, therefore, that, gratifying as they are in number and in the interest displayed, the replies to our inquiries present a wide diversity of experience and opinion. Neither is it strange that well-established facts are lacking in support of many of the opinions. Naturally there is general agreement as to the more or less disastrous effects of vibration, but few cases have been developed where the extent of the harm done is clearly shown in dollars and cents. Everything points, however, to the material advantages of rigidity in a structure and its proper insulation from external sources of vibration.

OUR PURPOSE

Although it is our purpose to embody the discussion and results in a comprehensive report, we hope, by immediately publishing the following general survey of the information already secured from various sources, to encourage further coöperation while we are continuing our study and experiments. We reserve for the final report that thorough analysis and weighing of evidence, together with the theoretical discussion and the experimental records which are vitally essential to a comprehensive understanding of the subject.

QUESTIONS ASKED

The original inquiry sent to a very considerable number of professional men and manufacturers asked —

"Whether you have been able to trace any effects to the vibration of buildings, and if so, what and in what types of construction?

"What experience you may have had with the effect of vibration in machines independently of building vibration.

"What suggestions or references you can offer that will assist us."

REPLIES RECEIVED

The replies to these questions as tabulated below show that about one third can be classed as informative. The balance, while expressing interest, professed lack of experience or were exceedingly general in their statements; for instance, merely affirming that vibration is harmful and that rigidity in construction is generally essential to its elimination, but giving no facts in evidence.

CANVASS OF REPLIES RECEIVED IN CONNECTION WITH INVESTIGATION OF EFFECTS OF VIBRATION

Groups	Informative	Non-Informative	Total
Editors,	12	44	56
Professors,	24	32	56
Engineers,	47	81	128
Boot and Shoe and Leather,	67	74	141
Textile Mills,	50	46	96
Metal Workers,	114	276	390
Paper Mills,	19	64	83
Chemical,	4	24	28
Food Products,	17	27	44
Miscellaneous,	22	89	111
Totals,	376	757	1,133

GENERAL ASPECTS OF SUBJECT

As was to be expected, the most precise information was received from those engaged in professional work, — the professors and engineers. But very few technical articles and no really comprehensive discussions have as yet been discovered which deal with the effects of vibration in buildings. It therefore seems well at this point to consider the general aspects of the subject before passing to a digest of the replies received through correspondence.

Distinction must first of all be made between those somewhat local vibrations of a structure produced by the intermittent

action of machines, the movement of trucks, etc., within its walls, and the more extended oscillations or tremors of the whole building generally transmitted from external sources.

NATURAL FREQUENCY OF VIBRATION

Every part of the building — beams, floor columns, walls, etc. (in fact, the entire building itself) — has its natural pitch or periodic number of vibrations which will result when it is set in motion. If the cause be intermittent and of a different frequency from that of the structural feature, the result will be a breaking up of vibrations except for those intervals when they get "in step," then the natural action will be exaggerated.

The effect of coincidence between the natural frequency of vibration of a floor and that of a source of disturbance is well illustrated by the following experience in connection with the testing of a small engine upon a floor of timber construction. At a speed of about 550 revolutions per minute, the intensity of the floor vibration was so great that it was impossible to work in the draughting-room located on the same floor more than a hundred feet away. But this effect entirely disappeared when the speed was either increased or decreased by about 50 revolutions. When the disturbing force is represented by a number of machines at practically the same speed, the effect may be like that of dancers upon a floor or soldiers marching over a bridge and prove most destructive to the entire structure, or most disordering to its contents or occupants, if the step time coincides with its natural pitch.

RECORDING VIBRATIONS

Obviously, most vibrations are the result of several components, and for actual analysis records must be made of not only the vertical but also the horizontal components both longitudinally and crosswise of the building. Vibration recorders are modeled on the principle of the seismograph originally developed from the study of earthquake phenomena. In the three-component type developed by Mr. Maurice Deutsch, C.E., of New York, and Prof. Elmer E. Hall, of the University of California, the whole design is much lighter than in the ordinary seismograph, thus rendering it capable of recording vibrations of much higher frequency than those occurring during an earth-

quake. The records are made on a rotating drum covered with smoked paper which may be fixed by dipping in an alcohol solution of shellac. The recorder, which may be placed at any position in the building, separates a given vibration into three components, two horizontal components at right angles to each other and the vertical component. These three components are recorded simultaneously.

The accompanying records, made by Mr. Deutsch and presented through his courtesy, indicate something of the results that may be obtained.

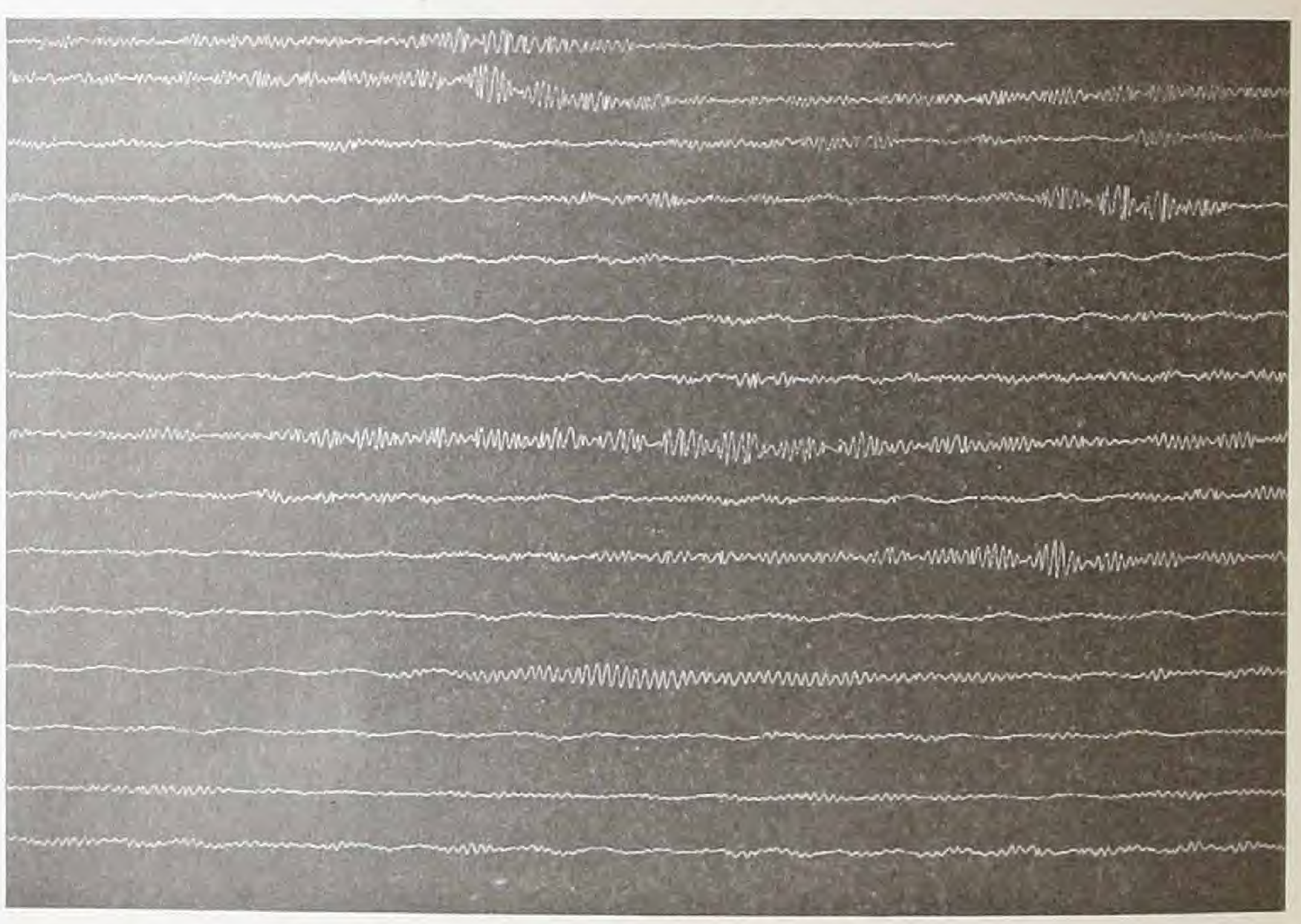

FIG. 1. This shows the vertical vibrations caused by the operation of passenger trains in a large railroad terminal of the best type of fire-proof floor and structural design. The records were taken on the fifth floor.

FIG. 2. This is a record — magnified 320 times — of the horizontal motions produced by a steam exciter on the turbine floor of a steel fire-proof building. A close examination of this record shows minute waves imposed upon the large ones, indicating the presence of a vibration having another period, much less in amplitude but far greater in frequency.

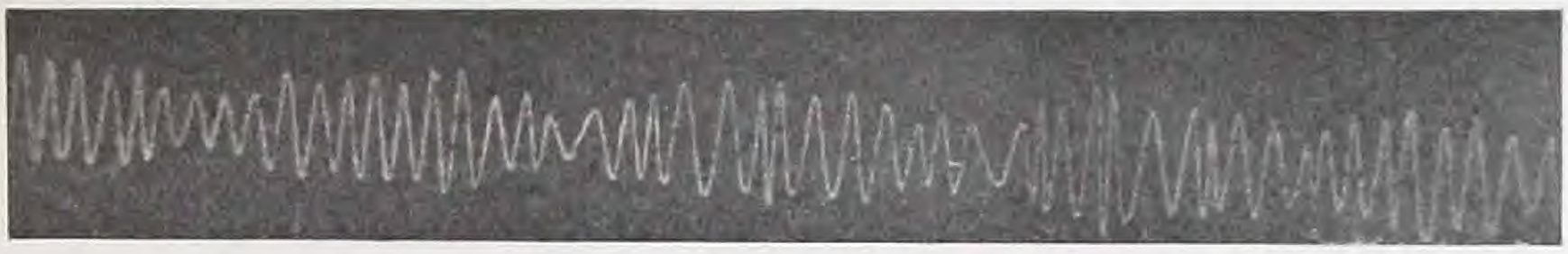

FIG. 3. This illustrates how a floor struggles to vibrate in its own period rather than that of the machinery. It records the vertical vibrations on the floor of a power station due to a large motor-generator, frequency 14.6 per second, double amplitude 0.08 mm. The concrete steel floor is supported by I-beams. The natural period of the floor is 12.4 per second, hence the effect of "beats."

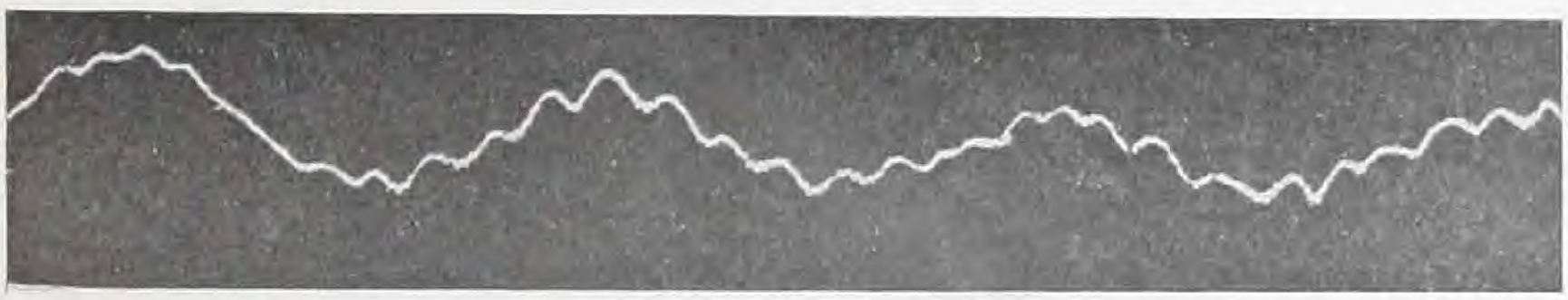

FIG. 4. This was taken at a time when three separate sources of vibration were distinct enough to be caught and measured. So far as we are aware, this is the first time that this was ever done by any instrument. The Vibration Recorder was placed upon the ninth floor of a steel frame office building. The three large waves show the relatively slow vibration of the building parallel to the street, while the smaller and more frequent waves, and the faint but nevertheless discernible still lighter waves imposed upon them show separately two effects of the operation of a steam turbine in an adjacent power house. The record is a suggestion of the certainty with which external sources of vibration may be determined.

CAUSES VS. EFFECTS

While such records, by serving to display the existence and magnitude of vibrations, are of immense value in tracing out the causes and thus making possible their elimination, we must look to other means for determining and measuring the specific effects. Although no one doubts that higher speed, better work, and greater human efficiency are possible in a stable as compared with a vibrating building, this investigation has already proven how difficult it is to obtain exact data which support this opinion. The reasons are not far to seek. It is seldom indeed that direct comparison can be made between machines or individuals operating in different buildings under otherwise identical conditions except that of vibration due to a difference in construction. Nor is it common practice to maintain such accurate records of performance that results obtained "before and after" vibration was eliminated can be compared. Above all, it is extremely difficult to judge of the effect on the human system,

when we consider that both motion and sound are produced by vibration and that humankind differs widely in physiological and psychological susceptibility. Nevertheless the information already secured through correspondence is such as to make manifest the vast economic importance of the reduction or practical elimination of vibration — particularly in buildings occupied for industrial purposes.

EFFECT OF TYPE OF CONSTRUCTION

Obviously, all discussion of the effects of vibration in structures must come back to a consideration of the type of construction and the extent to which it permits or prevents vibration. The context of many of the quotations which have been selected from a large volume of interesting material, as well as some of the quotations themselves, refers to buildings, usually old, entirely unsuited to the requirements. Hence the resulting vibrations. Naturally enough, conditions which would receive immediate attention in a modern manufacturing plant are often allowed to continue in an old structure. Other correspondence shows with equal clearness that the absence of vibrations is due to the rigidity of the structure, to foresight in the placing of certain machines on solid foundations, to the proper cushioning of others, and to such arrangements of duplicate machines operating at the same speed as to avoid cumulative effect.

CONDITIONS AS REPORTED

With the desire to encourage further discussion and draw out additional contributions of opinion and experience, some of the replies have been roughly grouped as to cause or effect so as to simplify analysis. But the number of replies is so great, and their character so diversified, that we may not hope, even in the complete report, to do them full justice. No attempt is made here to deduce final conclusions; but the effort has been to so present reported conditions, even if the statements are not conclusive, as to emphasize the necessity of seeking out fundamental causes if any benefit is to be derived from this investigation. It is not possible within the limits of this preliminary report to include the general context of running comment on types of building construction which forms a vital part of the correspondence. Suffice it to say that in most cases vibration is traced back

to faulty or unstable construction, and that the rigidity of steel and concrete in some form is generally regarded as essential to its prevention. But the flexibility of wooden construction and the failure to adequately "damp" or cushion the blows of vertical reciprocating machinery in the case of the more inflexible concrete construction somewhat obscure certain opinions as regards the desirability of the two types of structures.

Naturally, a great many correspondents have not clearly differentiated between cause and effect, nor between vibration existing only within the machine itself and that transmitted through the floor to or from the machine. But, on the other hand, they have shown a clear appreciation of the harmful effects of vibration and an interest in this investigation that is most encouraging.

MOTION OR SOUND AS RESULT OF VIBRATION

Because they are so important and at the same time so difficult to analyze, much interest centers about the effects upon machine operators and factory workers in general. These effects resolve themselves into two forms of manifestation. Which of these effects is produced — that of being felt or being heard — is determined mainly by the vibration frequency. Although there is no sharp dividing line and the extreme limits of audibility vary with the individual, they are usually given as between 16 vibrations and 45,000 vibrations per second. At the lower limit, the question of intensity becomes an important factor, and it is difficult to determine whether or not it is the ear alone or the whole body that detects the sound or vibration. Hence the annoyance from sound is not easily separated from the nervous exhaustion resulting from direct vibration. On the other hand, the physical or nervous effect may be substantially the same whether the cause is to be found in the particular machine which the worker is tending or the vibration be transmitted through the floor from a distance. Undoubtedly the reason for a considerable diversity of opinion as to the annoyance or harm resulting from vibrations lies in a failure to consider their frequency.

EFFICIENCY OF WORKERS REDUCED

The general experience is, that severe vibration "tends to tire the workmen and make them nervous, with the result that

they become irritable and inefficient." In one case where vibration occurred, the correspondent states that "it was necessary for us to take promptly the necessary steps to overcome it, as under certain conditions it was impossible for our employees to stand it for a very long time. This meant that if they had to work on a floor which was vibrating they were far from 100 per cent efficient. In the case of women, it seemed impossible for them to stand the vibration even temporarily on account of its nervous effect. We believe that employees working under such conditions as we had were not over two thirds efficient."

EMPLOYEES LEAVE ON ACCOUNT OF VIBRATION

The plant manager of a large concern says: "I have had four different clerks leave my employ because they could not stand the vibration of the building. During the past nine years I have lost a number of men (I should judge about eight or ten) from our chipping hammer floor. The effect of the vibration is such that the men could not do a day's work."

The direct effect of machine vibration is shown in the case of a mill-constructed building by this report of a shoe manufacturer: "I have known many instances of operators on high-speed shoe machines being obliged to stand on especially constructed stands in order to remove the vibration from their legs which had proved extremely tiresome." The same writer also refers to the operator of a rapid standard screw machine, who, "after several years of employment, suffered from paralysis of the legs which afterwards caused his death." He furthermore says, "I have heard of numerous complaints made by operators and have observed in some instances where they were of an extremely nervous type that they either had to change their occupation or have their machines moved to a place where the vibration was less."

VIBRATION CAUSES FRIGHT

Most disastrous is the feeling of fright that now and then occurs among the occupants of a peculiarly unstable building. One writer refers to the experience of having worked in a factory where "the vibration was so bad that there was a constant feeling of apprehension that the floor might give way." Another states that "on the fourth floor of the building the vibration

was so bad that it was hard work to get help that would stay in the room. This I attribute to fright." Obviously such conditions could only exist in buildings entirely unsuitable for manufacturing purposes.

MACHINE OUTPUT REDUCED

Closely related to the efficiency of the individual is that of the machine, which, in one way or another, is affected by vibration and, like the individual, displays the effect in decreased output. The correspondence reveals many cases.

An instructive contrast in conditions and results is shown in this letter from a consulting engineer: "Some years back we built and installed the apparatus in a weaving mill mainly for manufacturing narrow fabrics and elastic fabric, such as suspender elastic. The mill in which this plant was originally located was of the old-fashioned mill construction, but rather light, and the looms could not run over 120 picks per minute without serious difficulty with breaking threads. In fact, many of the looms had to be cut down to approximately 110 picks, in order to avoid serious loss in breakage. In the new plant the designed speed was about 145, but through an error on the part of the master mechanic it was made 160. When the plant was started, the superintendent made vigorous complaint that this speed would result in difficulty; but after running for about a week and the operatives getting used to the speed, no trouble was experienced, and it is our understanding that the mill is at present running at this speed with less loss, so far as breakage is concerned, than was experienced in the old mill at far slower speed, and, of course, with greatly increased output. This was due solely to lack of vibration."

STABILITY INCREASES OUTPUT

In the case of another textile mill the manufacturer says: "I have known of two instances in buildings of standard mill construction where a considerable loss was occasioned by vibration in the spinning room due to the roving unwinding while a frame was stopped. Looms will bang off frequently on a vibrating floor. Cards cannot be set as closely and consequently do as good work on a vibrating floor. Frames require more frequent lining and leveling where the building vibrates."

Another correspondent adds a postscript, reading as follows: "Since writing the above, the writer conversed with an engineer who made some changes in a factory building here in Scranton, to overcome vibration, and the parties concerned said to him afterwards that he had increased their production 50%."

A firm of consulting engineers and architects report regarding the occupation of a new reinforced concrete building by a printing company that "previous to their occupancy of this building their factory had been located in an old brick and wood building. They find that they can now run their presses 20% faster than in the old building. They also state that the reduction in vibration has increased the comfort and the efficiency of their employees and output of their machines."

SOLID FOUNDATIONS INSURE GREATER OUTPUT

In so far as the replies present definite facts regarding output, many of them also discuss the value of solid foundations. A typical case is presented in the following: "We would cite one machine which was first placed directly on the floor and vibrated very badly. In order to overcome this vibration we had the floor cut away around the machine and a foundation put under it. The increased output by making this change was almost 40%, due to the fact that the operator could take measurements with the machine running when there was no vibration, but was unable to do so where the vibration was so great. The quality of the work was also greatly improved."

Most statements regarding change in efficiency or output lack the evidence of definite measurements, but are nevertheless convincing, as, for instance, the following: "We had heavy machines in the second floor of a building which we were obliged to remove. In their new position they were placed on concrete foundations, and we believe that they not only did better work, as there was an abundance of vibration, but they did 25 to 30% more work."

TEXTILE MILL EXPERIENCES

"We think there can be no question," says a textile manufacturer, "but what cotton machinery is more efficient, and of longer life, when placed in substantial buildings and on rigid floors free from vibration. Especially is this true of looms. A

rigid loom placed on a firm foundation will turn out better work, and more of it, than one of lighter frame, subject in itself to vibration and standing on a vibrating floor. The same is true of carding machines, which all manufacturers agree should stand on a substantial and firm floor."

In this connection an engineer who has had wide experience in the measurement of vibrations and the study of its effects makes the following statement: "I have made some investigations as to the vibrations in some of our textile mills, and believe that one of the reasons, among others, perhaps, why some of the English and other foreign fabrics are better than some of the American fabrics is that greater attention has been given to the construction of floors, which are surprisingly free from disturbing vibrations; also the methods used for setting machines on the floors. Aside from the improvement in quality of the fabrics, it has been estimated that about 10% of increase in output may be effected in many known cases where disturbing vibrations exist in textile mills."

THE REWARD OF RECONSTRUCTION

An illustration of what can be accomplished by change in construction is presented by a writer who "recalls a reconstruction which we made several years ago where, by the placing of a new line shaft on good substantial foundations and rearranging the power plant in such a way as to keep machinery operating at rated speed constantly, the output was increased something over 15% without an increased cost for power or labor. This is simply an illustration of what can be accomplished by construction that is as near right as we are permitted to make it."

MACHINE-SHOP IMPROVEMENTS

Among several cases of specific statement regarding increased output is this contained in a letter relating to some large belted grinding machines: "We built the foundation for these machines through a basement, and after placing the machines upon the foundation we found we had not only cut out the building vibration entirely, but increased the grinding capacity of the machines possibly 10%, without using any more wheels. In other words, the wheels previously vibrated so that they caused the wear to be much more rapid than

it was after the machine was placed on a solid foundation and made to run true. Vibration in this particular case had not continued long enough to do any damage to the building, but it was so severe that it would be only a question of a short time until we would have had to repair the brick work."

The general effect of vibrations in machine shops is clearly expressed in the following: "With the heavier tools where there is an excessive amount of vibration, the depth of the cut is limited, and we cannot use the full power of the tools. It produces sort of a chattering, which marks the work and limits the amount of stock which can be removed in one cut."

DIFFICULTIES WITH LINE SHAFTING

Vibration is made responsible by many for waste of power and for difficulties with line shafting, but there is evidently some confusion between the weakness of a building which merely results in its sagging and the vibration directly traceable to lack of rigidity. The general condition is well expressed in the following quotation: "We have had some trouble from vibration in wooden buildings which may be of interest. This has been the usual difficulty of maintaining line shafting in alignment, particularly where hung under floors subject to heavy trucking loads, or to other loads due to piling the materials above the shafting. In some circumstances this has been so marked as to make it necessary to shorten the belts driving machines located below, or to piece them out, as the case may be. This condition we have no doubt has resulted in a considerable loss of power due to friction of bearings and also expense in maintenance."

VIBRATION LOSSES CONSIDERABLE

Although specific facts are not always presented, there is general confirmation of the opinion expressed by an industrial engineer as follows: "There is one point where I think the vibration of buildings is not considered sufficiently, and that is transmission of power by shafting. I believe the losses due to vibration in such transmission are considerable."

Direct evidence of the effect of mis-alinement through change in floor levels is shown in such statements as this: "We have often been obliged to reline shafting, and also, after

adopting higher rates of speed, we found it necessary to install additional posts supporting several floors."

A common experience is stated in these words: "We had a line shaft suspended from the roof. On account of the vibration in this shaft we were compelled to change it, as it was impossible to keep the shaft in line."

REPAIRS — A CONTINUOUS EXPENSE

An item of continuous expense referred to by many is that of repairs — comment being particularly with relation to their decrease or elimination through greater stability of floor or foundations. The contrast is well shown in the following quotation: "Our buildings are all of solid masonry construction in which the question of vibration has been handled competently, due to the fact that we use one-story type of buildings almost exclusively for manufacturing purposes. We, however, did experience in some of our old wooden structures a considerable amount of repair work upon one particular class of machines, due to the lack of adequate support under the machine. There has been a noticeable decrease in repairs upon this particular class of machines after being placed upon solid foundations."

MORE REPAIRS — LESS PRODUCTION

A textile manufacturer referring to certain buildings of mill construction but insufficient stability which were stiffened up by pilasters and new flooring stated: "The thing noticeable in these mills before such changes was that there was a great deal more repairs on looms and, therefore, necessarily, less production." Of course the repairs to the buildings themselves must also be considered under such conditions as outlined by the following correspondent, who states: "The buildings in our plant in which machines are installed, are old-fashioned brick buildings with floor joists resting on brick walls at each floor and on beams supported by columns between the walls. In all cases the loading of the floors is within the safe limits of the floor construction, but we have found that the vibrations in many instances have caused the loosening of the floor joist supports in the walls and have in some cases made repairs necessary to the building."

INTERFERENCE WITH DELICATE MEASUREMENTS

Of course there can be no question as to the disastrous effects of vibration when delicate measurements are to be made or fine work is to be done. Many cases are cited of the difficulty of doing accurate weighing on laboratory balances or even on ordinary scales when the building is subject to vibration. We are all familiar with the practice in technical laboratories of carrying balances on piers which in some cases are supported at the bottom of wells many feet beneath the surface where moving cars, trains, or machinery exert a disturbing influence. But this is usually impossible, as in the case of a large manufacturer who writes: "Our chemical laboratory was located on the sixth floor of a steel frame building, having concrete floor slabs and brick walls. There was considerable machinery operating on the floor below. The vibration here made it difficult to do accurate weighing on the laboratory balances when the machinery was in operation. We have since transferred this laboratory to the eighth floor of our new building 'C,' which you erected. There is very little machinery running in this new building and the laboratory has not been disturbed by vibration."

A consulting engineer tells that at the time one of his clients had some automatic buffing machines driven by belt "the vibration was so great that it was necessary for them to transfer the weighing scales into another building so that the operators could do accurate work."

ABSORBING VIBRATION

Resort has naturally been made to various absorbing materials for reducing vibration in balance scales. One party states, "The best results have been obtained by supporting the scales directly on sponge rubber, the scale table itself being supported on an independent brick pier isolated from the walls of the building."

The effect upon tool room work and the operation of fine machine tools is referred to by a considerable number, the general idea being expressed in the following: "Machines susceptible to disturbance by vibrations, such as grinding machines, are all mounted on solid foundations." One writer "recalls the vibration of the floor of a tool room which interfered with

the balancing of a grinder wheel 36 inches in diameter, and also of a case where a heavy cut on a planer caused vibration in the floor and put chatter into shafts which we were grinding on our heavy grinder."

A machine tool manufacturer bespeaks common experience when he says, "We have difficulty in taking fine measurements where very sensitive indicating mechanisms both mechanical and optical are used."

TRANSMISSION OF SOUND

One correspondent referring to transmission of sound says: "One other noticeable feature in the two buildings is that the sounds do not carry as readily in the concrete building as they do in the mill-constructed building. For instance, through the floors in the mill-constructed building you will be more annoyed by the workmen on the floor above than you are in the concrete building under the same condition." In interesting contrast as regards transmission in a concrete building is the following from another correspondent: "Our office building is concrete, with the office force on the first floor and implement sample room with concrete floor in the second story. We find that the noise due to iron-wheeled trucks on the second floor is very objectionable in the offices on the floor below, although this trouble could no doubt be overcome largely by the use of rubber-tired trucks."

In still further contrast is the following which illustrates the spirit of toleration with annoyance that becomes characteristic in many cases. Reference was made to punch presses on the fourth floor of a ten-story building with the statement: "The principal trouble we had was due to the excessive racket which the presses made. I do believe, however, that the shocks and noise interfered with the work of these punch presses themselves, and also with the rest of the work of the department."

CRYSTALLIZATION AS RESULT OF VIBRATION

In connection with the discussion of solid foundations, reference has already been made to the necessity of proper "damping" or cushioning, when there is a disturbing vertical reciprocating motion. Crystallization, as the direct effect of vibration resulting from the operation of non-cushioned machines,

is noted by several. Says one manufacturer: "When we find the vibration of a machine objectionable, we use rubber pads between the machine and the concrete floor." The writer has the idea that this cuts down the crystallization of the machines.

A shoe manufacturer, referring to some of their heavier machines, such as sole cutters, that are placed in the basement on cement floors, states that even with "six-inch wood between the floor and machine, we find that they crystallize and break much quicker than the machines did before we had concrete floors."

TRACING VIBRATION TO EXTERNAL SOURCES

Most difficult to overcome, and in many cases most difficult to trace, is the vibration transmitted from sources outside the building. Many interesting cases have been brought to light through the correspondence, the full discussion of which would require far more space than can be given in this preliminary report.

Experience with the effect of passing trains is so common as to hardly need comment here, but there is certain novelty in the following report regarding vibration in a laboratory only twenty feet distant from a four-track trunk railway: "A large part of our trouble emanating from the vibration due to passing of trains apparently results from an underground stream, as we notice maximum movement when trains are crossing this stream at a point nearly two blocks distant. Some years ago the stream was an open brook, later filled in, and the railroad tracks elevated above the street grade some twenty feet, but the vibrations noted above are still apparent, somewhat modified, however, by the number of trains and direction of movement in the front of our property."

SOIL AND ROCK FORMATION

Of course the soil and rock formation upon which buildings rest must be studied carefully in tracing out transmission of vibration from a distance. In a well-known college with an underlying stratum of rock upon which most of the building foundations rest, there is annoying vibration in dormitories several hundred feet from passing trains and also in buildings some distance from and on a much higher level than the lighting plant.

A large manufacturer who states that the ground is mostly gravel writes that "metallographical observations under a powerful microscope are considerably disturbed in a detached brick building, due to soil vibrations, notwithstanding that the hammer shop is several hundred feet away."

The personal experience of one correspondent is particularly interesting as suggesting atmospheric transmission. "My residence is about one-half mile from the dam across the Merrimack River in Lawrence, and at certain times, with air conditions right and a certain quantity of water flowing over the dam, I have felt a vibration at my house and the windows have rattled distinctly, caused by the water flowing over the dam."

VIBRATION IN CONGESTED COMMUNITIES

Particularly in congested communities the transmission of vibration is taking on a serious legal aspect, as evidenced by this case: "The operation of presses caused such serious vibration in a building about 200 feet away as to endanger the structure and seriously affect its tenancy. The court finally granted the plaintiff a complete injunction against the owners of the printing establishment. After certain changes were made in the printing plant the vibrations were entirely eliminated."

The situation is clearly presented in the following extract from an article by Mr. Maurice Deutsch, C.E., who has made a very large number of vibration records, of which a few have been reproduced on previous pages of this report:

"Vibrations have of late been absorbing the attention of not only scientists but of the general public in large cities. Since the introduction of skyscrapers towering far above adjoining buildings, of large printing plants and power houses, diversified complaints of vibrations are frequently heard. Subway trains now penetrating rock and then the softest quicksands and the operation of heavy bed presses and reciprocating engines leave in their path a tremor to which many adjoining buildings are so naturally attuned that the vibrations are often not only annoying, but dangerous both to the building in which the machinery may be operating and to adjoining structures. One sometimes finds special localities to which vibrations are carried strongly, while places nearer to the source may be relatively free from trouble.

"In concrete steel monolithic structures, when properly designed, the entire mass acts as a unit to absorb vibrations, the

main tendency being to set up an oscillatory motion of the entire structure; but this can generally be avoided if proper foundations are constructed, and if such precautions are taken in the location, arrangement, and operations of the moving machinery as have been found from experience would materially reduce the possible transmission of vibrations.

"There are numerous buildings occupied by printing and other trades requiring moving machinery which are producing vibrations in adjoining buildings, causing serious damage as well as creating a nuisance. Such trouble could be easily avoided if careful study were given to the location and operation of such machinery, and the bed or foundation upon which it rests. Often such vibration continues unnoticed for a long time, unquestionably causing deterioration in the building as well as affecting the output of the machine and the quality of the work done."

As already stated, it is not our purpose here to present conclusions, neither is it our desire to express our personal opinions. We have, therefore, drawn from the correspondence a very considerable number of extracts which represent both extremes as well as the general concensus of opinion, and have endeavored through brief comment to clear up the reasons for some differences of opinion.

INDIVIDUAL EXPERIENCE AS BASIS OF JUDGMENT

First of all, it is manifest that approval or disapproval of certain types of construction depends very largely upon individual experience. There is no particular reason why a person should criticise an ordinary building of wood with joist floors if little or no moving machinery is operated within it, or if that machinery is such and so arranged as to produce no noticeable vibration under any conditions.

A textile manufacturer of long experience with mill construction says: "I have seen mill buildings vibrating so much from the movement of machinery that a half-filled pail of water placed upon the upper floor would spill over, and still I do not think that the machinery was running at a disadvantage." But in contrast is this statement from the superintendent of another large mill: "We have a very large three-story brick mill, and the vibration affects the running of the machinery to a great extent. I notice this more especially on the top story, where the spinning is located. We have had a great deal of

trouble from vibration of the ring rails breaking down the ends. This vibration tends to increase power, too, by throwing out of alignment the machinery and shafting. My experience has been that all brick buildings vibrate more or less, and the only remedy I can suggest would be to build our future factories of heavy reinforced concrete. This seems to be the prevailing opinion of our best engineers." Both of these statements should be considered in the light of other quotations previously made with regard to repairs and output.

CHARACTER OF MACHINERY DETERMINES SUITABILITY OF BUILDING

To what extent the character of machinery operated determines the suitability of any type of building construction is evidenced by the following. A shoe manufacturer writes: "We formerly had our clicking machines, which are used in cutting upper leather, on our top floor of a mill-constructed building. The vibration was so great that we were forced to put trusses underneath the floor; but later we put up a solid concrete building and transferred this same department to the top floor of this building and have experienced no trouble from this source ever since."

Another shoe manufacturer has "had experience in the three different types of construction, — joist, mill, and concrete, — and found the best results from the concrete construction. At the present time we are in a mill-constructed building and assure you it gives very poor service, especially in the cutting department, where they use a number of clicking machines that strike a heavy blow."

FOUNDATION VS. SOLID FLOORS

A machinery manufacturer says: "We found it necessary to remove milling machines and gear cutters from a balcony which was of mill construction and place them on the ground floor, where we built concrete foundations for them."

On the other hand, where there is heavy reciprocating machinery or ponderous geared rolls and the like, it is manifest, as one correspondent expresses it, that "too great rigidity is not to be desired, as far as floors are concerned, for a large variety of machines." Hence the quite general practice of

placing machines on concrete foundations. But mere removal from the concrete upper floor of a concrete building to ground level foundations may not overcome the effect of vibration, for, as a shoe manufacturer says, "We have had trouble and have heard of other firms having trouble with dieing-out machines which were set on concrete basement floors, there being so little spring in the setting, in response to the heavy hammer of the head of the machine, that the frame of the machine is apt to break."

OVERCOMING JAR

The possibility of overcoming the jar or vibration due to heavy presses on upper floors of concrete buildings is well illustrated by the following experience: "We have had a great deal of difficulty in our concrete buildings due to the vibration from certain classes of machinery. We have in mind particularly the sheet metal working presses and shears which are placed on the fourth floor of one of our new concrete buildings. The vibration from these seems to be just the right amplitude to produce a disagreeable and even dangerous effect through the entire building. We have finally put large rubber pads underneath all of these presses and we think that this has largely overcome the difficulty, although in shearing heavy plates there is still a very appreciable vibration." In further explanation these manufacturers say: "The concrete building to which we referred is of slab and girder construction and is built in a most substantial manner. The presses are operated at a very low speed, we would say from 30 to 50 revolutions per minute. The vibration, however, is rather due to the shock at the instant of cutting steel sheets."

FORESIGHT ESSENTIAL IN DESIGN

It is manifest from the preceding and numerous other references in correspondence, some of which have already been quoted, that much of the trouble caused by reciprocating machinery may be eliminated by proper cushioning or bracing. The following quotation from a well-known firm of designing engineers displays the requisite foresight: "In a general way when we design our work we have in mind the character of the machinery which is to be used on the various floors. Where machinery

creates more or less vibration due to shock, etc., an effort is generally made to use either a massive construction to absorb the shock or else put in direct supports which will transmit the vibration to a point below the foundation."

REINFORCED CONCRETE ELIMINATES VIBRATION

Statements regarding the comparative merits of different types of construction cover a wide range of experience and opinion. Thus in the case of a knitting mill it is stated that "we have had considerable trouble with combination beam and joist construction buildings; we have found that buildings of a modern type mill construction have almost entirely overcome the vibration; in our reinforced concrete constructed buildings we have heavy machines on the first and second floors and have never had any sagging or dropping of the floors, nor do we have any vibration whatever."

While certain leather manufacturers refer to trouble from vibration in wooden buildings, the writer of the following says, "In our plant, which is entirely of reinforced concrete, we have not found any serious vibration of any kind." Comparison between types is thus drawn by a motor car manufacturer: "Timber construction of what is known as slow burning mill type with wooden posts and beams is very prone to vibration. Gear cutting machines or grinders cannot be as successfully used here as in a building of reinforced concrete design."

EFFECT OF MACHINE DESIGN

As already stated, the extent to which a building may contain vibration-producing machinery must, of course, affect one's judgment of the value of different types of construction. One paper manufacturer states that "we have considerable vibration in one of our mill buildings, due to machines in operation. This building is of standard mill construction. In justice we should state that the machine causing the greater part of this vibration is of peculiar design and construction, and is the only one we have. Were it located in other mills similar effects would be experienced, except possibly with heavy reinforced concrete construction."

MORE OPINIONS REGARDING REINFORCED CONCRETE

A cereal manufacturer refers to "a case of a certain type of flour sifter which we use — one of which is used in a building of regular mill construction, and the other used in a building of concrete construction; that the one in the mill construction building has given us considerable trouble, due probably to vibration of the floor, while the one in the concrete building has run for several years with practically no repairs."

The replies include a very considerable number of statements from consulting and designing engineers, ranging from the opinion that there are no material advantages in a reinforced concrete building to the following: "The owners had some mill construction buildings in use before we built the reinforced concrete buildings. Some sections of the former vibrated like drums, but we believe the concrete construction has proven quite free from vibration."

FURTHER COOPERATION SOLICITED

And so the comment runs, and a great volume more might be added. We hope, however, that even in the form in which it has been presented it may be of value to those who read, but, above all, that it will encourage those who are directly interested to share their experiences with us. We shall welcome correspondence and shall be glad to send the complete report to all responsible parties who express a desire for it.

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